RESEARCH DEPARTMENT

The simulation of some delay-unit defects in a field-store standards conversion system

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THE SIMULATION OF SOME DELAY-UNIT DEFECTS IN A FIELD-STORE STANDARDS CONVERSION SYSTEM

Research Report No. T-152

(1965/41)

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SUMMARY

A proposed method of converting between television standards having different field frequencies utilises cascaded ultrasonic fused-quartz delays. The picture impairment associated with distortion or spurious signals introduced by individual delays would be increased by the switching in or out of combinations of delay; this switching is an inherent part of the conversion process.

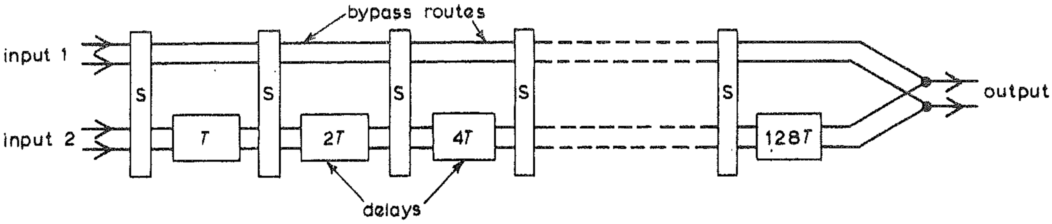
This report discusses the various types of distortion and spurious signals which may be present and describes an experiment which simulated the more important effects. The results suggest that frequency modulation of the ultrasonic carrier would be desirable because of the accurate matching of the gain of individual delay units that would be demanded by the use of amplitude modulation.

1. INTRODUCTION

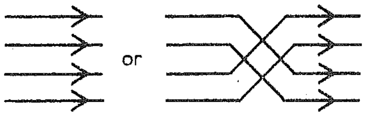
A recently described method[1] of converting signals from the American 525-line, 60 fields per second standard to the European 625-line, 50 fields per second standard, and vice versa, makes use of a number of delay units each capable of delaying a video signal by tens or hundreds of microseconds. It is proposed to use fused-quartz ultrasonic delays for this purpose but these delays suffer from a number of imperfections that can cause distortion of the converted signal. In order to assess the practicability of this method of field-store standards conversion, apparatus was constructed to simulate some of the effects of delay-unit imperfections. The result of the effects on the displayed output picture has been studied and a subjective experiment carried out in order to assess the extent to which delay-unit imperfections can be tolerated.

2. THE CONVERSION SYSTEM

In one version of the proposed conversion system,[1] lines of the input signal are delayed by integral multiples of T (where $T = 66.2/3\ \mu s$); all multiples of T from 0 to 250T are required for conversion from 525/60 to 625/50 and all multiples from 0 to 300T are required for conversion from 625/50 to 525/60. Conversion from 525/60 to 625/50, which is mainly considered here, demands eight delay units while conversion

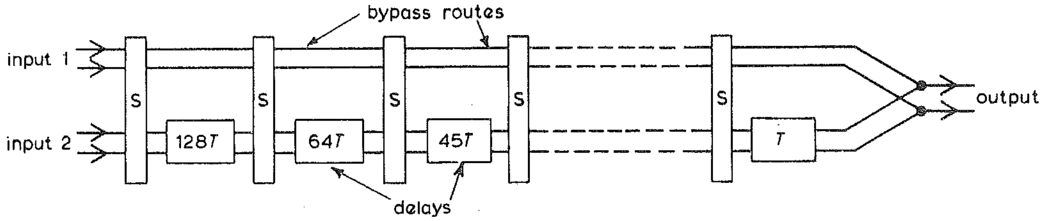


Notes: (A) Each switch 'S' can be operated to give alternative connections



(B) Eight delays in binary sequence
(C) $T = 66\frac{2}{3}\,\mu s$

(a)



Notes: (A) Switches as in (a) above.
(B) Nine delays (eight in binary sequence and one of 45T)
(C) $T = 66\frac{2}{3}\,\mu s$

(b)

Fig. 1 - Arrangement of binary main store

(*a*) Main store arrangement for 525/60 to 625/50 conversion
(*b*) Main store arrangement for 625/50 to 525/60 conversion

from 625/50 to 525/60 demands nine units. The required signal delays are obtained from various combinations of the delay units. The arrangements of the delay units, for both types of conversion, are shown in Fig. 1. The duration of the delay provided by each unit is a binary multiple of T (i.e. 2^r . T where r is an integer). Each delay unit may be by-passed so that a signal may pass through the delay unit or not according to the setting of an electronic switch. It is shown in Ref. 1 that, with this arrangement, it is possible to obtain a signal delay which is any integral multiple of T up to the maximum value required and that a switching sequence can be devised which delays the sequence of line signals in the manner required for field-store standards conversion.

For conversion from 525/60 to 625/50, sequences of five or six input lines are delayed by multiples of T and each sequence is delayed by an interval which is greater, by T, than that suffered by the previous sequence; the signal delay thus increases steadily from zero to 250T. A complete input field is then discarded and the delay returns to zero.

For conversion from 625/50 to 525/60, sequences of six or seven input lines are delayed by multiples of T and each sequence is delayed by an interval that is less, by T, than that suffered by the previous sequence; the signal delay thus decreases steadily from 300T to zero. A complete field is then repeated, the delay for the first sequence of that field being 300T.

By expressing the delay required for any particular sequence of lines as the product of T and an integer expressed as the sum of powers of two, the actual delays in circuit for the sequence may be determined; moreover, by considering in this way the delays required for a number of successive sequences, the switching pattern for any particular delay unit may be determined. The shortest delay T is required whenever the least significant digit of the integer, when expressed as a binary number, is one (i.e. the integer is odd). Thus, the shortest delay is alternately switched in and out of circuit for successive sequences. The next longer delay, of duration 2T, is switched in and out of circuit half as often as the shortest delay and, likewise, each of the longer delays is switched into circuit just half as often as the next shorter delay. At the end of each 0·1 sec period (i.e. the period occupied by six fields of the 525/60 standard and five fields of the 625/50 standard) the action is interrupted and the switching process started afresh.

3. DISTORTIONS DUE TO DELAY UNITS

The signal to be delayed modulates an r.f. carrier and the modulated carrier is propagated, as an acoustic wave, in each quartz block. The carrier frequency may lie between 20 Mc/s and 60 Mc/s and both a.m. and f.m. have been suggested as modulations systems.

Each delay unit consists of a driving amplifier, input transducer, quartz block, output transducer and output amplifier and it is necessary to take into account the distortions due to the amplifiers as well as those due to the quartz block itself. The relevant properties of the delay units are listed below:

(i) Attenuation

The transducers and quartz blocks introduce attenuation of the order of 50 dB and amplifiers are provided to offset this attenuation. The stability of attenuation of the transducers and quartz is of the order of 0·03 dB per degree centigrade[2] and this is considerably higher than the gain stability normally achieved by amplifiers. Thus the stability of gain is mainly dependent on the amplifiers.

(ii) Delay

Delays between about 30 μs and 4 ms can be achieved with a single quartz block. Delay units longer than approximately 4 ms demand the use of several quartz blocks and associated amplifiers in tandom. The delay stability of a delay circuit depends on the temperature stability of the quartz block since the delays of the amplifiers are short and do not change significantly. The variation of quartz-block delay with temperature is quoted as 75 parts per 10^6 per degree centigrade.[2] With a temperature controlled oven, a stability of about 0·01°C may be achieved so that the delay stability should be about 0·75 ns per 1 ms delay.

(iii) Unsatisfactory transmission characteristics as functions of frequency

The group-delay characteristic of a quartz delay as a function of frequency is uniform but its amplitude-response characteristics as a function of frequency is non-uniform and is usually corrected to be as constant as possible over the passband by means of a lumped-constant network; after correction there may be residual small ripples in the characteristic. The amount of amplitude-response correction is normally quite small and is not thought to give rise to significant variations of group-delay with frequency.

(iv) Noise

Delay circuit noise is principally due to the amplifiers; the quartz blocks and transducers do not contribute significantly. The characteristics of the noise obtained after demodulation depends on whether a.m. or f.m. is used. As is well known with a.m., the noise spectrum is unchanged by demodulation but with f.m. a flat r.f. noise spectrum produces video noise with a triangular spectrum. The characteristics of the noise will also be altered if r.f. pre-emphasis and de-emphasis are used.

(v) Spurious response

Unwanted reflections of the signal during transmission through the quartz block give rise to spurious signals which are added to the main signal. These are usually more than 40 dB down on the main signal and, for quartz blocks with delays of the order of milliseconds, may be numerous and well-separated in time from the main response.

4. SIMULATION APPARATUS

Distortion of the signal can arise due to differences between the transmission characteristics of a delay unit and its associated by-pass circuit, and the main function of this apparatus was to simulate these differences in order that their effects could be observed on a displayed picture and subjective tests carried out to assess their perceptibilities.

Accordingly, the video signal was suitably switched either to a path which contained circuits simulating the transmission characteristics of a practical fused-quartz delay unit or to a path consisting of a simple direct connection (see Fig. 2).

The electronic switch was controlled by waveforms derived from a number of bi-stable circuits and locked to line- and field-frequency pulses; the required switching waveforms can be derived as described in Section 2 and are illustrated in Fig. 3. Since only one set of apparatus simulating a delay unit was available, it was possible to study the effects for only one delay unit at a time. As the patterns produced on a television display by the delay/by-pass switch-waveforms corresponding to a simulated 625/50 to 525/60 conversion are essentially similar to those for a 525/60 to 625/50 conversion, it was necessary to perform only the experiments corresponding to the latter; for convenience it was decided to simulate the switching patterns occurring in a 525/60 to 625/50 conversion as this required a source of 625/50 signals which was readily available.

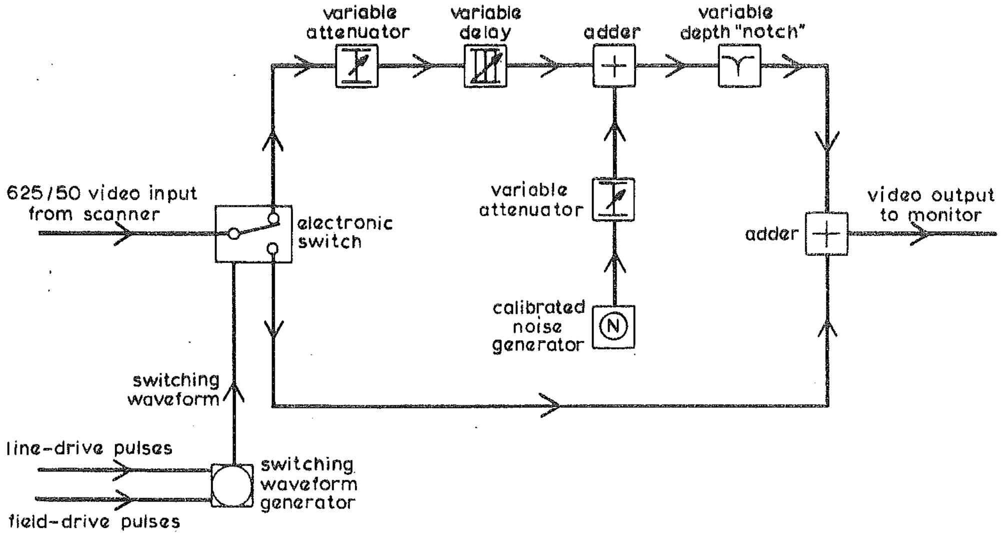
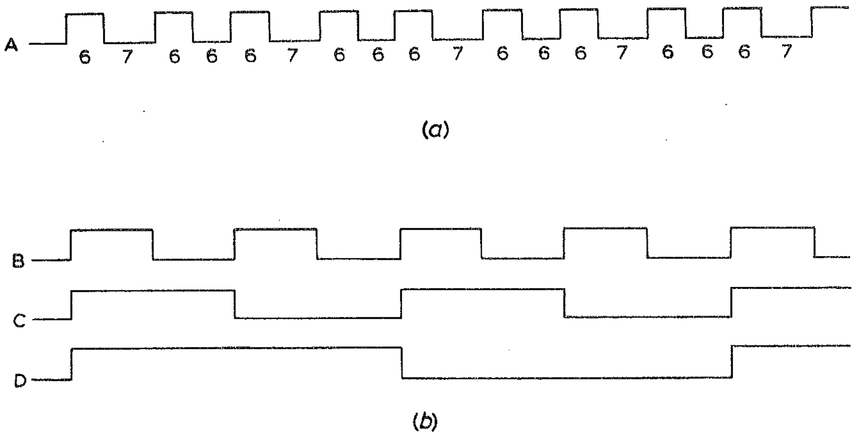


Fig. 2 - Simulation apparatus



(*a*)

(*b*)

Fig. 3 - Switching waveforms

(*a*) Primary waveform derived from Line Sync Pulses. This sequence was continued throughout five fields and after five fields the sequence was restarted. (This simulated the action of the switch controlling the delay unit of delay T in a practical standards converter.)

(*b*) Secondary waveforms derived by bistable counting circuits from A, B, C and D simulated the action of switches controlling delay units of delay 2T, 4T and 8T in a practical standards converter. Waveforms simulating switches controlling remaining delay units were obtained by further counting circuits working in like manner.

Each distortion listed in Section 3 contributes to distortion of the final video signal. In the experiment video signals were used throughout and it was therefore necessary to provide distortions of the video signal representing those that would have occurred had a modulated carrier signal traversed an imperfect delay unit.

The following distortions could be introduced in one of the alternative signal paths:

(i) Attenuation: variable in steps of 0·05 dB to simulate a gain error in a delay unit.

(ii) Delay: variable in steps of 5 ns.

(iii) Unsatisfactory transmission as a function of frequency: 'notch' circuits producing a ripple in the response as a function of frequency. A number of such characteristics were available as shown in Fig. 4. The centre frequencies were 0·5 Mc/s and 2 Mc/s, the corresponding 3 dB point widths were 0·5 Mc/s and 2 Mc/s, and the notch 'depth' was variable from 0·1 dB to 2 dB.

(iv) Noise: obtained from a calibrated noise source. Its amplitude could be varied and either a flat or a triangular spectrum could be chosen.

A reasonably realistic simulation of spurious responses was not possible since the spurious signals are sometimes numerous and widely separated from the main response and the simulation apparatus would therefore itself require a number of long delays.

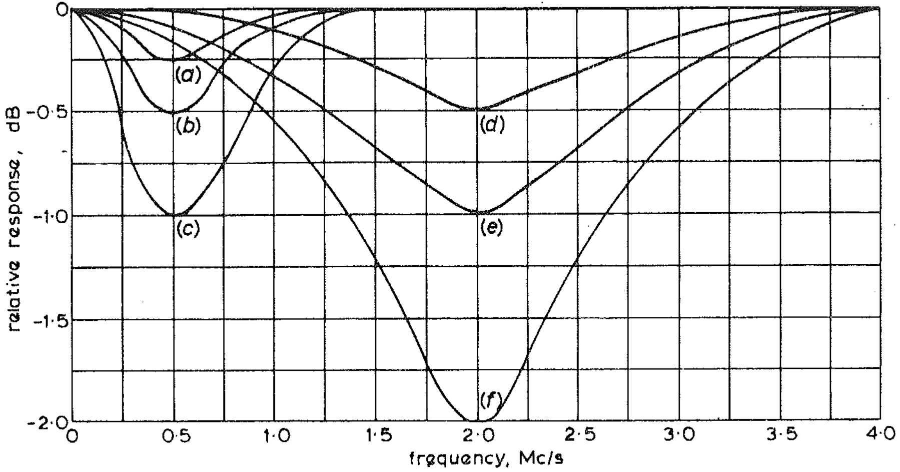


Fig. 4 - Transmission characteristics of networks used to simulate response of quartz delays

(*a*), (*b*), (*c*) - centre frequency = 0·5 Mc/s; depth = - 0·25 dB, - 0·5 dB, - 1·0 dB respectively
(*d*), (*e*), (*f*) - centre frequency = 2·0 Mc/s; depth = - 0·5 dB, - 1·0 dB, - 2·0 dB respectively

5. EXPERIMENTS

5.1. Appearance of Switching Patterns

Initially, one of the two paths through which the signal could pass was broken so as to produce a black area on the picture when the particular circuit path was engaged by the switch. This enabled the patterns due to switching to be clearly observed and classified for each of the delay-switching cycles in turn. It was noted that the patterns consisted of moving horizontal bars of varying height. The main characteristics of the appearance of the resulting pattern for each switching cycle are described below:

1st delay: (delay T, i.e. 67 μs to the nearest μs)
Narrow horizontal bars, changing position up and down cyclically at 5 c/s

2nd delay: (delay 2T)
Narrow horizontal bars flickering at 25 c/s

3rd, 4th and 5th delays: (delays 4T, 8T and 16T)
Broad horizontal bars moving rapidly upwards

6th, 7th and 8th delays: (delays 32T, 64T and 128T)
Flicker at 10 c/s with some horizontal bars

5.2. Subjective Assessment of the Visibility of Distortions

Subsequently, subjective experiments were carried out in order to determine the perceptibility of each form of distortion for three of the eight switching patterns. These corresponded to the delays of T, 4T and 128T and were selected because the observers rated these the three most visible patterns.

The picture source was a slide scanner, Test Card 'C' was used as the test picture and standardized viewing conditions were maintained throughout.* In each set of tests, ten skilled observers were first shown a sample of fairly gross distortion and then asked to assess the perceptibility of varying amounts of these distortions using a subjective scale having the three grades given below:

1. Imperceptible
2. Perceptible with difficulty
3. Perceptible without difficulty

This scale should not be confused with the first three grades of the six-point impairment scale normally used in the BBC. It was used partly because pictures giving grades greater than 3 would not be worth considering and also because the observers found some difficulty in interpreting grade 3 of the impairment scale ('Definitely perceptible but not disturbing') in relation to the unusual nature of the interference under consideration here. Some patterns were always disturbing if they were perceptible.

In the first set of tests each form of distortion was applied separately at a number of levels in order to determine the variation of mean grade with level. Subsequently, the distortions were combined together with each distortion at a level corresponding to a mean grade of approximately 1·5, in order to assess the extent to which combinations of the effects further degraded the picture.

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* Observers at a distance of five times picture height from the screen.
White : 25 ft Lamberts.
Ambient (measured on white card) : 0·5 ft Lamberts.

6. TEST RESULTS

The results of the subjective tests are shown in Table 1 below. The figures correspond to the levels of distortion giving mean grades of 1·5, 2 and 2·5 and were obtained, by interpolation, from the mean grades corresponding to the levels of distortion tested. The mean grades were repeatable to within about 0·4 of a grade and the standard error is given in the extreme right-hand column.

In a subsequent test, all four types of distortion, attenuator errors, delay errors, noise and non-uniformity of frequency response were imposed simultaneously. The amount of each distortion corresponded to a mean grade of 1·5 and the combined effect resulted in a mean grade of 2·2. This indicates that if no individual distortion is worse than the grade 1·5 level the combined impairment will be just perceptible.

7. INTERPRETATION OF RESULTS

In assessing the overall effect that would occur when each form of distortion is present and eight delays are in use, as in a practical converter, it is reasonable to suppose that most of the effects add incoherently since their effects upon the output picture are mostly dissimilar. On this basis, for example, the overall effect of equal distortion contributions from all eight delays is equivalent, in effect, to $\sqrt{8}$ times the distortion due to a single delay. It is possible to deduce a specification for the delays in terms of the forms of distortion tested by deciding upon the maximum subjective grade permissible and dividing the appropriate distortion level by $\sqrt{8}$. This will be unduly pessimistic if one expects the distortion to be significant only in certain of the delays but adjustments may be made accordingly.

Each type of distortion is now considered separately assuming that a mean subjective grade of 1·5 overall is acceptable.

7.1. Attenuation Errors

Attenuation errors are automatically removed if f.m. or phase modulation is used but if a.m. were used the attenuation error after demodulation would be equal to that in the modulated-signal path. The variation of attenuation in fused quartz with temperature is well within 0·05 dB (the value corresponding to a mean subjective grade of 1·5 in Table 1) under expected operating conditions (temperature controlled to within 0·01°C) so that significant variations of attenuation will occur only in amplifiers and switches. Hence, if no A.G.C. is used, the attenuation accuracy and stability for each delay must be ± 0·003 (± 0·025/8 dB), while if A.G.C. is used, the overall attenuation must be held to within ± 0·025 dB. By using the best available techniques, it is thought unlikely that this tolerance can be met. Thus, it will be possible to use a.m. only if improved techniques for maintaining gain stability are forthcoming.

7.2. Delay

The results for delay errors apply directly to either a.m. or f.m. The delay error is proportioned to the delay and consequently the longest delays have the

TABLE 1

TYPE OF DISTORTION	SWITCHING PATTERN									STANDARD ERROR
	T DELAY MEAN GRADE			4T DELAY MEAN GRADE			128T DELAY MEAN GRADE			
	1·5	2	2·5	1·5	2	2·5	1·5	2	2·5	
Attenuation error	0·06 dB	0·08 dB	0·1 dB	0·04 dB	0·06 dB	0·08 dB	0·06 dB	0·08 dB	0·1 dB	0·02 dB
Delay error	10 ns	15 ns	20 ns	10 ns	15 ns	20 ns	10 ns	15 ns	20 ns	5 ns
Flat spectrum noise. S/N ratio	44 dB	42 dB	40 dB	44 dB	42 dB	40 dB	40 dB	38 dB	36 dB	2 dB
Triangular spectrum noise S/N ratio	38 dB	37 dB	35 dB	37 dB	35 dB	34 dB	35 dB	34 dB	32 dB	2 dB
Depth of notch in amplitude characteristic centred at 0·5 Mc/s	0·25 dB	0·4 dB	0·6 dB	0·25 dB	0·4 dB	0·5 dB	0·25 dB	0·4 dB	0·6 dB	0·1 dB
Depth of notch in amplitude characteristic centred at 2 Mc/s depth	1 dB	1·5 dB	2 dB	1 dB	1·5 dB	2 dB	1 dB	1·5 dB	2 dB	0·5 dB

most significant effect. The tolerance for the longest delay should therefore be 10 ns, corresponding to a mean subjective grade of 1·5. If the temperature of each quartz block is maintained to within 0·01°C and the temperature variation of delay is, say, 75 parts per 10^6 per degree centigrade,[2] the tolerance on the longest delay will be within 7 ns which is just adequate.

In an ideal converter there will be systematic timing errors of the order of 3 μs.[1] The necessary correcting device may be either servo-controlled or logic-controlled and if servo-controlled could also reduce errors due to the delays themselves, thus removing the necessity for highly accurate temperature control.

7.3. Noise

If a.m. is used flat-spectrum r.f. noise added to the signal produces flat-spectrum video noise after demodulation, but if f.m. is used flat-spectrum noise results in triangular-spectrum noise after demodulation. The signal-to-noise power ratio depends on the depth of modulation used in each case and would be some 10 dB worse for f.m. than for a.m. since the bandwidth available only permits small deviaations. In a subsidiary experiment in which continuous noise was compared with switched noise, the results for continuous noise were consistent with previous results.[3] For discontinuous noise the visibility depends on the rate of switching. For high switching rates, which are associated with the short delays, the noise appears, with full visibility, in horizontal bands in the picture and at zero visibility between these bands. Under these conditions it is slightly more visible than continuous noise at the same peak level. For low switching rates of the order of 10 c/s, which are associated with the long delays, the noise is evenly distributed spatially in the picture but is removed from the signal for some fields and not others. Under this condition, the eye integrates the noise giving the subjective impression of continuous noise at 3 dB lower level. In a converter, most of the noise would be contributed by the long-delay units, each of which may contain more than one quartz block and hence more amplifiers contributing noise than in the case of a short delay. The specification for delay-unit signal-to-noise ratio should be deduced from the results given in the table for the long delays. In the converter, the eight delay units would probably be provided by a total of twelve quartz blocks and twelve amplifiers. Thus, for a mean grade of 1·5, an overall signal-to-noise ratio of 40 dB would be required if a.m. were used, and the signal-to-noise ratio for a single amplifier would therefore have to be $(40 + 10 \log_{10}12)$ dB, i.e. 51 dB; i.e. twelve cascaded amplifiers each having a signal-to-noise ratio of 51 dB would give an overall signal-to-noise ratio of 40 dB. If f.m. were used, the signal-to-noise ratio of the recovered video signal would have to be not less than 35 dB (triangular spectrum). Allowing 10 dB for low deviation, the signal-to-noise ratio for a single amplifier would then have to be 56 dB. However, r.f. pre-emphasis could be applied to the f.m. sidebands before passing the signal through the delay units, and de-emphasis applied after delay. The result would be to reduce the noise at the higher video frequencies and the noise spectrum would then become less triangular and have lower power. It is likely that, by this means, similar overall signal-to-noise ratios could be obtained with either a.m. or f.m.

7.4. Spurious Responses

In practice, spurious signals remote in time from the main signal may be numerous, and may vary considerably in time and magnitude with carrier frequency.

Also the resultant of adding a spurious signal to the main signal depends on relative carrier phases of the main and spurious signals and is totally different for a.m. and f.m.

In an amplitude-modulated system, it is not possible to control the carrier frequency so as to ensure that the main-signal and spurious-signal carriers always bear a quadrature relationship. Therefore, it is necessary to assume that a spurious response causes an increase or decrease in the magnitude of the output signal, according to the phase of the spurious signal carrier, and its appearance would be similar to that of a ghost due to multipath propagation; however, the spurious response would be modulated with the appropriate switching pattern. Suppose that a particular part of the output picture results from a main signal corresponding to a large plain area and a spurious signal from a large plain area elsewhere in the picture. The spurious signal would be switched on and off according to the switching pattern of the delay which produced it. The amplitude of the combined signals would be modulated at the switching frequency and the appearance of the picture would be similar to that produced by a gain error in the defective delay. The tolerance to gain error for a mean grade of 1·5 was found to be about 0·05 dB or approximately 0·5% which is equivalent to the addition of a spurious signal 46 dB down on the main signal. Hence, it is reasonable to say that any spurious response whose magnitude was greater than 0·5% of that of the wanted signal would be visible occasionally. In practice, owing to the number of delays used, there may be several spurious signals of such magnitude. This will increase the visibility of the spurious responses and a maximum level of 0·5% for spurious responses cannot be regarded as safe.

For f.m. the appearance of a spurious signal is difficult to predict. However, by considering the f.m. wave produced by adding together a large-amplitude frequency-modulated carrier and a small-amplitude frequency-modulated carrier it may be shown that the presence of spurious responses cannot give a d.c. error in the signal and it would be expected therefore that spurious responses result in less visible effects for f.m. than for a.m., since errors in l.f. signal components with frequencies of the order of, say, 100 kc/s have been shown to be more visible than errors in h.f. components with frequencies of the order of several Mc/s.[4] Further work is needed to determine a suitable specification for spurious responses if f.m. were used.

7.5. Response as a Function of Frequency

The measured values for permissible deviation from uniformity of the response may be applied directly to a.m. The variation of response must be much smaller for low modulating frequencies than for high modulating frequencies. The k-ratings of the distorting networks were measured using the 2T pulse test. The 0·5 Mc/s notch had a k-rating of 0·5%, and the 2 Mc/s notch a k-rating of 2%, for notch 'depths' corresponding to a mean grade of 1·5. The required response cannot therefore be conveniently defined in terms of k-rating but a k-rating of 0·5% would appear to be adequate. The fact that these results are not in accord with those obtained when similar distortions are present continuously would suggest that switching exaggerates the effects of low frequency gain and phase errors. Table 1 shows that a 0·25 dB error at 0·5 Mc/s and a 1 dB error at 2 Mc/s result in a mean grade of 1·5. In the past, the amplitude responses, as functions of frequency, of quartz delays have been corrected to within 0·25 dB over the whole band. This figure is adequate for modulating frequencies greater than, say, 1 Mc/s but would have to be improved upon for lower modulating frequencies in order to take account of the combination of effects from all the delays.

The transient response for an f.m. system has not been adequately analysed in the general case. Further theoretical and practical work is needed in order to determine the response, as a function of frequency, required for a given performance. However, it is thought unlikely that the distortion would be significantly worse for f.m. than for a.m.

8. CONCLUSIONS

The specifications for delay circuits with regard to stability of attenuation, transmission characteristics as a function of frequency, signal-to-noise ratio and stability of delay have been determined. All are important if a.m. were used although stability of attenuation would be unimportant if f.m. were used. An estimation of the required level for spurious signals has been given for the case of a.m. and it has been suggested that the conditions could be relaxed somewhat for f.m.

The design of quartz blocks permits some exchange between attenuation and spurious signal level, lower attenuation being accompanied by higher spurious signal level and vice versa. The attenuation directly affects the signal-to-noise ratio and it seems likely that the figures for signal-to-noise ratio can be easily met but that the figures for spurious-signal level will be more difficult to meet; the usual figure quoted for the magnitudes of spurious responses in a typical delay unit is 1%. The use of f.m. is therefore favoured from the point of view of spurious signals.

The quartz stability required may be met with good temperature control of the quartz blocks but servo-control on the delay may relax the temperature control requirements.

The gain stability required by an a.m. system demands sophisticated techniques. In this respect, f.m. is favoured since small variations in r.f. level do not affect the demodulated signal.

The transmission characteristics as functions of frequency can be met, for an a.m. system, using conventional correction techniques. In the case of f.m., not enough is yet known. Theoretical analysis appears to be exceedingly difficult and it will be necessary to construct a delay circuit using a f.m. system so that the requirements can be determined experimentally.

Further practical work is also necessary in order to assess the visibilities of spurious signals in an f.m. system.

9. REFERENCES

1. 'A Field-Store Converter Using Ultrasonic Delays as Storage Media', BBC Research Department Report No. T-136, Serial No. 1964/65.

2. BROCKLESBY, C.F., PALFREEMAN, J.S. and GIBSON, R.W.: 'Ultrasonic Delay Lines', (Iliffe, 1963).

3. '405-Line and 625-Line Television Pictures : The Relative Impairment Produced by Random Noise', BBC Research Department Report No. T-102, Serial No. 1962/45.

4. 'Pattern Visibility in Television Co-channel Interference', BBC Research Department Report No. T-091, Serial No. 1962/26.

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